Experimental report

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Proposal: **DIR-154** **Council:** 4/2017

Title: Magnetic coupling in Ordered CoFe2O4 Nanoparticle Layers

Research area: Materials

This proposal is a new proposal

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Samples: $CoFe_2O_4$

Instrument	Requested days	Allocated days	From	To
D17	6	5	29/03/2018	03/04/2018

Abstract:

Magnetic coupling of ordered $CoFe_2O_4$ nanoparticle layers

Magnetic nanostructures receive great attention currently as they are interesting both due to potential applications, e.g. in information technology and spintronics [1] and for the fundamental investigation of dipolar/exchange coupling [2]. In particular stacked structures of ordered magnetic nanoparticle monolayers are interesting due to their potential for highly structured 3D devices and as model systems for the study of nanoscale magnetism. For single domain magnetic nanoparticles arranged in a dense square lattice, local electron holography experiments and numerical simulations show that dipolar interaction can lead to a super antiferromagnetic coupling on the nanoscale [3, 4].

Polarized neutron reflectometry (PNR) was used to study four double layer nanostructures with varied interlayer distances, as well as a single layer reference sample. Square magnetic nanoparticle arrangements were prepared for this purpose by controlled evaporation-induced self-assembly of cobalt ferrite nanocubes on 1x1 cm^2 silicon substrates. The double layer samples are prepared by sequential deposition of two nanoparticle layers with insertion of a non-magnetic intermediate layer. The PNR experiments were performed on the D17 instrument in time-of-flight mode at 5 K after zero-field cooling the samples and without polarization analysis. PNR was measured at guide field (10 mT), at saturating field (6 T) and at a negative field (-100 mT). A q-range of 0 – 0.2 $Å^{-1}$ is covered by measuring the samples under incident angles of 0.50°, 1.80° and 4.00°. The smallest incident angle is measured 30 mins for each polarization channel, and the higher incident angles are measured at least for 1 h to improve counting statistics. For the single layer sample, the highest incident angle has not been measured, and the initial magnetic field measurement for the double layer prepared with the smallest PMMA concentration was skipped. The data is reduced with the COSMOS software [5] and shown in Fig. 1.

In each case the samples reveal a negligible splitting between the two polarization channels in the initial state, a strong clear splitting of both channels at saturation and a weaker splitting at the negative field. At the negative field, I^- shows a higher intensity in comparison to I^+ at q_z values above the critical angle, which is inverse to the observation at saturation. This is in agreement with the expectation from the wide hysteresis of the cobalt ferrite nanocubes, which after saturation have their magnetic superspins at weak negative fields antiparallel to the external field direction.

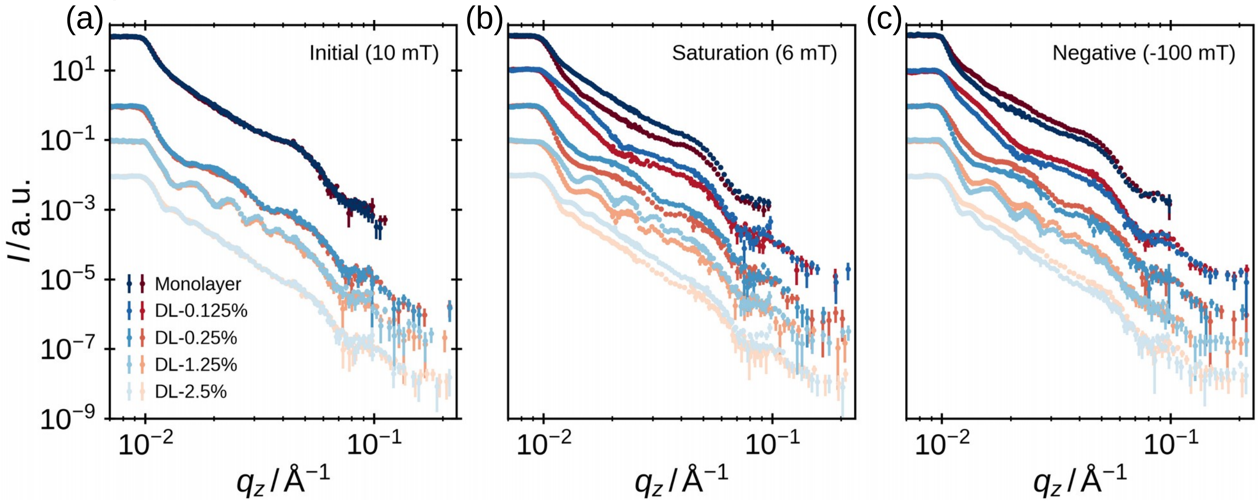

Fig. 1: PNR of a single layer and double layers of nanocubes in square arrays with varied interlayer distance measured at 5 K after zero-field cooling at (a) guide field, (b) saturation and (c) while applying a negative field.

Furthermore, the data shows for the double layer samples Kiessig fringes in addition to the structure that is visible in the monolayer sample. The period of the fringes in q_z decreases with increasing thickness of the spacer layer.

The clear separation of both neutron channels in all double layer cases suggests that ferromagnetic coupling dominates in all samples.
A quantitative evaluation of the data by modeling the nuclear and magnetic scattering length density profiles is on-going. We expect thereby in this first study to achieve a better understanding of the magnetic coupling between nanoparticle layers with respect to layer distance, which will be of great value for the future design of layered two-dimensional nanoparticle assemblies.

References:

[1] S. Sun *et al.*, *Science* **287**, 1989 (2000).
[2] D. Mishra *et al.*, *J. Phys.: Condens. Matter* **27**, 136001 (2015).
[3] M. Varón *et al.*, *Sci. Rep.* **3**, 1234 (2013).
[4] V. Russier, *J. Appl. Phys.* **89**, 2 (2001).
[5] P. Gutfreund *et al.*, *J. Appl. Cryst.*, **51**, 1–10 (2018).